The EUMETSAT Network of Satellite Application Facilities

H SAF
Support to Operational Hydrology and Water Management

Italian Meteorological Service

Italian Department of Civil Defence

H-SAF Product User Manual (PUM)

SM-OBS-2 - Small-scale surface soil moisture by radar scatterometer

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

TU WIEN
Vienna University of Technology Institut für Photogrammetrie und Fernerkundung

RMI
Royal Meteorological Institute of Belgium

European Centre for Medium-Range Weather Forecasts

Finnish Meteorological Institute

SYKE
Finnish Environment Institute

TKK
Helsinki University of Technology

Météo-France

LATMOS
CNRS Laboratoire Atmosphères, Milieux, Observations Spatiales

CESBIO
CNRS Centre d'Etudes Spatiales de la BIOsphere

bfg Bundesanstalt für Gewässerkunde
Bundesanstalt für Gewässerkunde

OMSZ
Hungarian Meteorological Service

ISAC
CNR - Istituto Scienze dell'Atmosfera e del Clima

Università di Ferrara

Institute of Meteorology and Water Management

Romania National Meteorological Administration

SHMÚ
Slovak Hydro-Meteorological Institute

Turkish State Meteorological Service

Middle East Technical University

Istanbul Technical University

Anadolu University

31 August 2010

H-SAF Product User Manual PUM-08
Product SM-OBS-2
Small-scale surface soil moisture by radar scatterometer

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Acronyms

ASAR	Advanced Synthetic Aperture Radar (on Envisat)
ASAR GM	ASAR Global Mode
ASCAT	Advanced Scatterometer (on MetOp)
ATDD	Algorithms Theoretical Definition Document
AU	Anadolu University (in Turkey)
BfG	Bundesanstalt für Gewässerkunde (in Germany)
BUFR	Binary Universal Form for the Representation of meteorological data
CAF	Central Application Facility (of EUMETSAT)
CC	Correlation Coefficient
CDA	Command and Data Acquisition station
CESBIO	Centre d'Etudes Spatiales de la BIOsphere (of CNRS, in France)
CM-SAF	SAF on Climate Monitoring
CNMCA	Centro Nazionale di Meteorologia e Climatologia Aeronautica (in Italy)
CNR	Consiglio Nazionale delle Ricerche (of Italy)
CNRS	Centre Nationale de la Recherche Scientifique (of France)
CORINE	COoRdination of INformation on the Environment
DPC	Dipartimento Protezione Civile (of Italy)
DWD	Deutscher Wetterdienst
EARS	EUMETSAT Advanced Retransmission Service
ECMWF	European Centre for Medium-range Weather Forecasts
Envisat	Environmental Satellite
ESA	European Space Agency
EUM	Short for EUMETSAT
EUMETCast	EUMETSAT's Broadcast System for Environmental Data
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbit
GMES	Global Monitoring for Environment and Security
GRAS-SAF	SAF on GRAS Meteorology
H-SAF	SAF on Support to Operational Hydrology and Water Management
IFOV	Instantaneous Field Of View
IMWM	Institute of Meteorology and Water Management (in Poland)
IPF	Institut für Photogrammetrie und Fernerkundung (of TU-Wien, in Austria)
IR	Infra Red
IRM	Institut Royal Météorologique (of Belgium) (alternative of RMI)
ISAC	Istituto di Scienze dell'Atmosfera e del Clima (of CNR, Italy)
ITU	İstanbul Technical University (in Turkey)
LATMOS	Laboratoire Atmosphères, Milieux, Observations Spatiales (of CNRS, in France)
LEO	Low Earth Orbit
LSA-SAF	SAF on Land Surface Analysis
LST	Local Solar Time (of a sunsynchronous orbit)
ME	Mean Error
Météo France	National Meteorological Service of France
MetOp	Meteorological Operational satellite
METU	Middle East Technical University (in Turkey)
MTF	Modulation Transfer Function
MW	Micro Wave
NMA	National Meteorological Administration (of Romania)
NOAA	National Oceanic and Atmospheric Administration (Agency and satellite)

NWC	Nowcasting
NWC-SAF	SAF in support to Nowcasting & Very Short Range Forecasting
NWP	Numerical Weather Prediction
NWP-SAF	SAF on Numerical Weather Prediction
O3M-SAF	SAF on Ozone and Atmospheric Chemistry Monitoring
OMSZ	Hungarian Meteorological Service
ORR	Operations Readiness Review
OSI-SAF	SAF on Ocean and Sea Ice
Pixel	Picture element
PNG	Portable Network Graphics
PUM	Product User Manual
PVR	Product Validation Report
REP-3	H-SAF Products Valiadation Report
RMI	Royal Meteorological Institute (of Belgium) (alternative of IRM)
RMSE	Root Mean Square Error
SAF	Satellite Application Facility
SAR	Synthetic Aperture Radar
SD	Standard Deviation
SHMÚ	Slovak Hydro-Meteorological Institute
SYKE	Suomen ympäristökeskus (Finnish Environment Institute)
TKK	Teknillinen korkeakoulu (Helsinki University of Technology)
TSMS	Turkish State Meteorological Service
TU-Wien	Technische Universität Wien (in Austria)
UniFe	University of Ferrara (in Italy)
URL	Uniform Resource Locator
UTC	Universal Coordinated Time
VIS	Visible
WARP-H	WAter Retrieval Package for hydrologic applications
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (of Austria)

1. Introduction to H-SAF

1.1 The EUMETSAT Satellite Application Facilities

H-SAF is part of the distributed application ground segment of the "*European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)*". The application ground segment consists of a "*Central Application Facility (CAF)*" and a network of eight "*Satellite Application Facilities (SAFs)*" dedicated to development and operational activities to provide satellite-derived data to support specific user communities. See ***Fig. 01***.

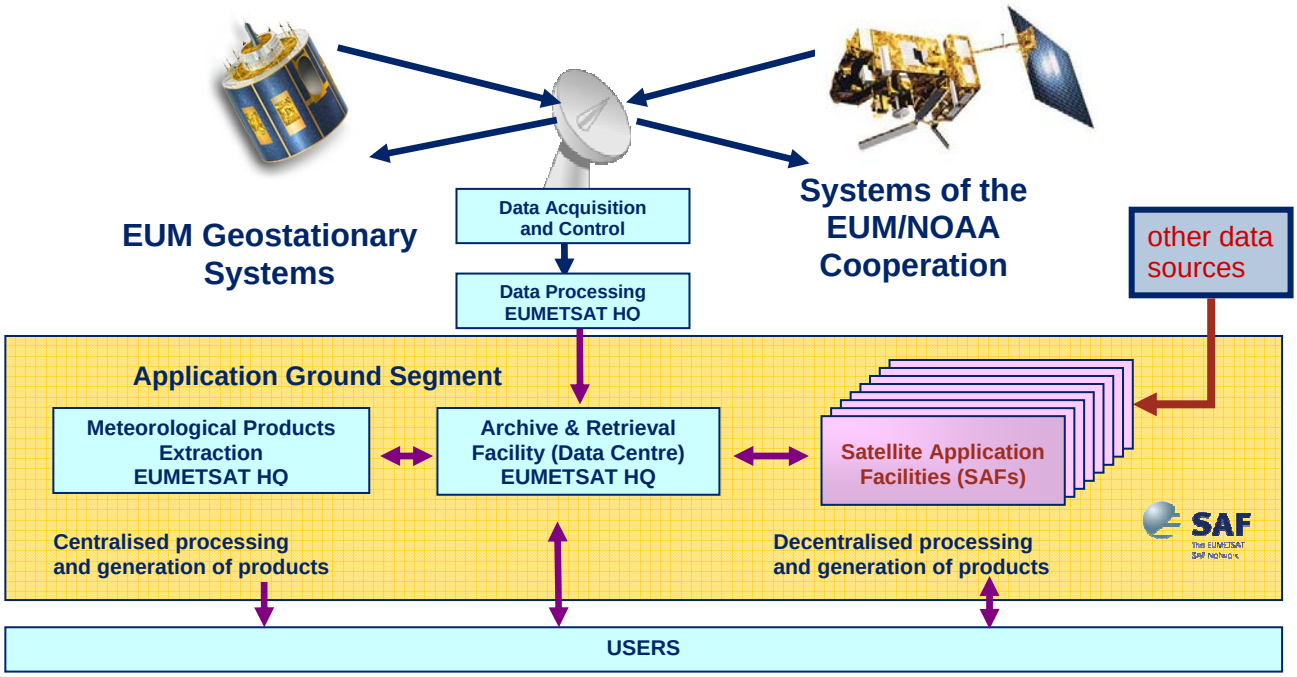
EUM Geostationary Systems
Data Acquisition and Control
Data Processing EUMETSAT HO
Systems of the EUM/NOAA Cooperation
other data sources
Application Ground Segment
Meteorological Products Extraction EUMETSAT HQ
Archive & Retrieval Facility (Data Centre) EUMETSAT HQ
Satellite Application Facilities (SAFs)
SAF
Centralised processing and generation of products
Decentralised processing and generation of products
USERS

Fig. 01 - Conceptual scheme of the EUMETSAT application ground segment.

Fig. 02 reminds the current composition of the EUMETSAT SAF network (in order of establishment).

NWC SAF	OSI SAF	O3M SAF	CM SAF	NWP SAF	GRAS SAF	LSA SAF	H SAF
Nowcasting & Very Short Range Forecasting	Ocean and Sea Ice	Ozone & Atmospheric Chemistry Monitoring	Climate Monitoring	Numerical Weather Prediction	GRAS Meteorology	Land Surface Analysis	Operational Hydrology & Water Management

Fig. 02 - Current composition of the EUMETSAT SAF network (in order of establishment).

1.2 H-SAF objectives and products

The "*EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF)*" was established by the EUMETSAT Council on 3 July 2005. Its Development Phase started on 1st September 2005 and ends on 31 August 2010. The work programme makes distinction between two Phases:

- Phase 1: products development, prototypes generation, preliminary validation.
- Phase 2: regular production, extended validation, hydrological validation.

The H-SAF objectives are:

a. ***to provide new satellite-derived products*** from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology; identified products:

- precipitation (liquid, solid, rate, accumulated);

- soil moisture (at large-scale, at local-scale, at surface, in the roots region);
- snow parameters (detection, cover, melting conditions, water equivalent);

b. to perform independent validation of the usefulness of the new products for fighting against floods, landslides, avalanches, and evaluating water resources; the activity includes:

- downscaling/upscaling modelling from observed/predicted fields to basin level;
- fusion of satellite-derived measurements with data from radar and raingauge networks;
- assimilation of satellite-derived products in hydrological models;
- assessment of the impact of the new satellite-derived products on hydrological applications.

This document (the PUM, Product User Manual) is concerned only with the satellite-derived products. The list of products to be generated by H-SAF is shown in ***Table 01.***

Table 01 - List of H-SAF products

Code	Acronym	Product name
H01	PR-OBS-1	Precipitation rate at ground by MW conical scanners (with indication of phase)
H02	PR-OBS-2	Precipitation rate at ground by MW cross-track scanners (with indication of phase)
H03	PR-OBS-3	Precipitation rate at ground by GEO/IR supported by LEO/MW
H04	PR-OBS-4	Precipitation rate at ground by LEO/MW supported by GEO/IR (with flag for phase)
H05	PR-OBS-5	Accumulated precipitation at ground by blended MW and IR
H06	PR-ASS-1	Instantaneous and accumulated precipitation at ground computed by a NWP model
H07	SM-OBS-1	Large-scale surface soil moisture by radar scatterometer
H08	SM-OBS-2	Small-scale surface soil moisture by radar scatterometer
H09	SM-ASS-1	Volumetric soil moisture (roots region) by scatterometer assimilation in NWP model
H10	SN-OBS-1	Snow detection (snow mask) by VIS/IR radiometry
H11	SN-OBS-2	Snow status (dry/wet) by MW radiometry
H12	SN-OBS-3	Effective snow cover by VIS/IR radiometry
H13	SN-OBS-4	Snow water equivalent by MW radiometry

The work of products generation is shared in the H-SAF Consortium as follows:

- Precipitation products (pre-fix: PR) are generated in Italy by the CNMCA, close to Rome.
- CNMCA also manages the Central Archive and the Data service.
- Soil moisture products (pre-fix: SM) are generated in Austria by ZAMG in Vienna, and at ECMWF; all derive from a Global surface soil moisture generated by EUMETSAT and transmitted worldwide via EUMETCast.
- ZAMG extracts SM-OBS-1 covering the H-SAF area from the EUMETSAT Global product, and generates SM-OBS-2 by disaggregating SM-OBS-1.
- ECMWF generates a Global volumetric soil moisture by assimilating the EUMETSAT Global product, and distributes its worldwide according to its data policy; then extracts SM-ASS-1 covering the H-SAF area.
- Snow products (pre-fix: SN) are generated in Finland by FMI in Helsinki, and in Turkey by TSMS in Ankara. Products from FMI and TSMS cover the full H-SAF area, but then they are merged (in FMI) in such a way that the flat and forested areas stem from the FMI product, the mountainous ones from the TSMS product. Exception: product SN-OBS-2 is only generated by FMI.

Table 02 deploys the user community addressed by H-SAF products.

Table 02 - User community addressed by H-SAF products

Entity	Application	Precipitation	Soil moisture	Snow parameters
Operational hydrological units	Fluvial basins management	Early warning of potential floods.	Landslides and flash flood forecasting.	Evaluation of flood damping or enhancing factors.
	Territory management	Extreme events statistics and hydrological risk mapping.	Soil characterisation and hydrological response units.	Dimes and exploitation of snow and glaciers for river regime regularisation.
		Public works planning.		
	Water reservoirs evaluation	Inventory of potential stored water resources.	Monitoring of available water to sustain vegetation.	Dimes and exploitation of snow and glaciers for drinkable water and irrigation.
National meteorological services	Numerical Weather Prediction	Assimilation to represent latent heat release inside the atmosphere.	Input of latent heat by evapotranspiration through the Planetary Boundary Layer.	Input of radiative heat from surface to atmosphere.
		Evaluation of NWP model's skill.		
	Nowcasting	Public information on actual weather.	Warning on the status of the territory for transport in emergencies.	Warning of avalanches.
		Warning for fishery and coastal zone activities.		Tourism information.
		Warning for agricultural works and crop protection.		Assistance to aviation during take-off and landing.
	Climate monitoring	Representation of the global water cycle in General Circulation Models.	Monitoring of desertification processes.	Monitoring glacier extension.
				Monitoring changes of planetary albedo.
Civil defence	Preparation for emergencies	Progressive level of attention function of rainfall monitoring.	Monitoring soil moisture growth.	Monitoring snow accumulation.
		Preparation of facilities and staff for a possible emergency.	Planning of in-field activities for event mitigation.	Planning of in-field activities for event mitigation.
	Emergency management	Alert to population.	Operational conditions for transport and use of staff and mitigation facilities.	Operational conditions for transport and use of staff and mitigation facilities.
	Post-emergency phase	De-ranking of alert level and monitoring of event ceasing.	Withdrawing of staff and mitigation facilities.	Withdrawing of staff and mitigation facilities.
			Assessment of vulnerability to possible event iteration.	Assessment of vulnerability to possible event iteration.
Research & development activities	Meteorology	Improved knowledge of the precipitation process.	Assessment of the role of observed soil moisture in NWP, either for verification or initialisation.	Assessment of the role of observed snow parameters in NWP, either for verification or initialisation.
		Assimilation of precipitation observation in NWP models.		
	Hydrology	Downscaling/upscaling of satellite precipitation observations.	Downscaling/upscaling of satellite soil moisture observations.	Downscaling/upscaling of satellite snow observations.
		Fusion with ground-based observations.	GIS-based fusion with ground-based observations.	GIS-based fusion with ground-based observations.
		Assimilation and impact studies.	Assimilation and impact studies.	Assimilation and impact studies.
	Civil defence	Decisional models for the alert system.	Organisational models for operating over moist soil.	Organisational models for operating over snow.

1.3 Evolution of H-SAF products

One special requirement of the H-SAF work plan was that the Hydrological validation programme, that started downstream of products availability, lasts for a sufficient time There was therefore a need to make available as soon as possible at least part of the products, accepting that their status of consolidation was still incomplete, the quality was not yet the best, and the characterisation was still poor due to limited validation. According to EUMETSAT definitions, the status of development of a product is qualified as in ***Table 03***.

Table 03 - Definition of the development status of a product according to EUMETSAT

In development	Products or software packages that are in development and not yet available to users
Demonstrational	Products or software packages that are provided to users without any commitment on the quality or availability of the service and have been considered by the relevant Steering Group to be useful to be disseminated in order to enabling users to test the product and to provide feedback
Pre-operational	Products or software packages with documented limitations that are able to satisfy the majority of applicable requirements and/or have been considered by the relevant Steering Group suitable for distribution to users
Operational	Products or software packages with documented non-relevant limitations that largely satisfy the requirements applicable and/or have been considered by the relevant Steering Group mature enough for distribution to users

The need for early release of products to activate the Hydrological validation programme as soon as possible led to define a stepwise approach for H-SAF products development. This is shown in ***Fig. 03***.

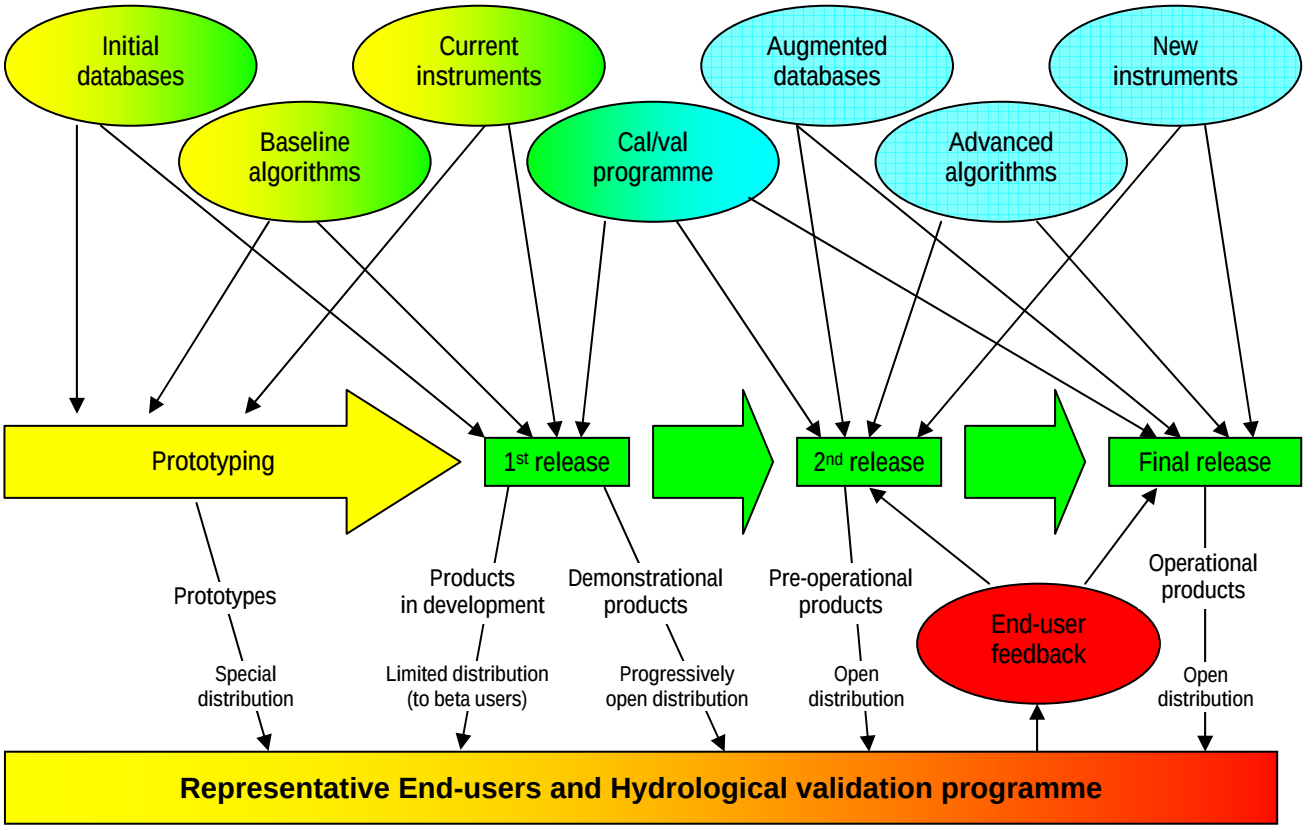

Fig. 03 - Logic of the incremental development scheme.

The time reference for this work plan is as follows:

- after approximately two years from the start of the Project (i.e. starting from the nominal date of 1st January 2008) a substantial fraction of the products listed in Table 01 are released first as "in development" and then after, as soon as some validation is performed, as "demonstrational";
- in the remaining three years the Hydrological validation programme builds up and grows. Mid-time, i.e. in mid-2009, the products of the first release are supposed to become "pre-operational", and the products missing the first release reach at least a demonstrational status. All products should become "operational" at the end of the Development Phase (31 August 2010).

Until the products are in the development status, their distribution is limited to the so-called *beta users*. Demonstrational, pre-operational and operational products have open distribution.

It is fair to record that not all products have been able to follow this schedule. Therefore, at the end of the Development Phase, the status of "in development", "demonstrational", "pre-operational" and "operational" will apply differently to the different products.

1.4 User service

In this section a short overview of the User service is provided, in terms of product geographic coverage, data circulation and management, Web site and Help desk.

1.4.1 Product coverage

Fig. 04 shows the required geographic coverage for H-SAF products. This area is fully covered by the Meteosat image (although the resolution sharply decreases at higher latitudes) each 15 min. For polar satellites, the area is covered by strips of swath approximately 1500 km (conical scanners) or 2200 km (cross-track scanners) at about 100 min intervals. Swaths intercepting the acquisition range of direct-read-out stations provide data in few minutes; for swaths outside the acquisition range the delay may be several tens of minutes if the satellite/instrument data are part of the EARS / EUMETCast broadcast, some hours otherwise (e.g., by ftp). The time resolution (*observing cycle*) is controlled by the number of satellites concurring to perform the observation, and the instrument swath.

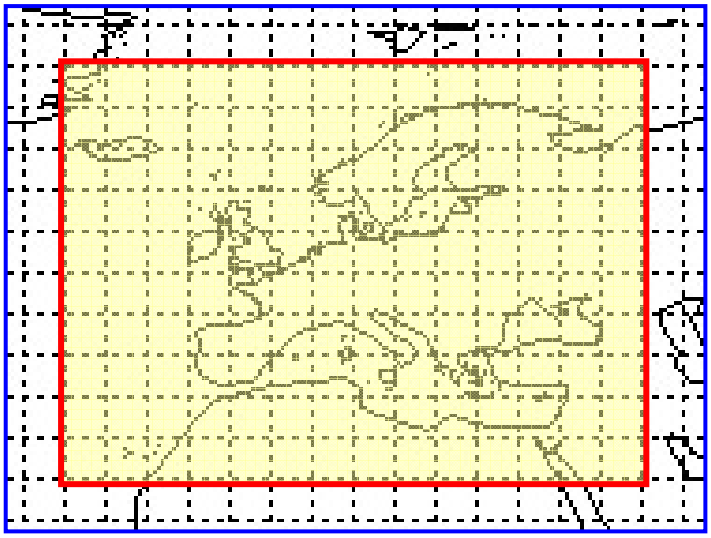

Fig. 04 - Required H-SAF coverage: 25-75°N lat, 25°W - 45°E

1.4.2 Data circulation and management

Fig. 05 shows the data circulation scheme in H-SAF. All products from the generating centres are concentrated at CNMCA (except that certain can go directly to the user by dedicated links: example, GTS, Global Telecommunication System connecting operational meteorological services). From CNMCA the data are sent to EUMETSAT to be broadcast by EUMETCast in near-real-time.

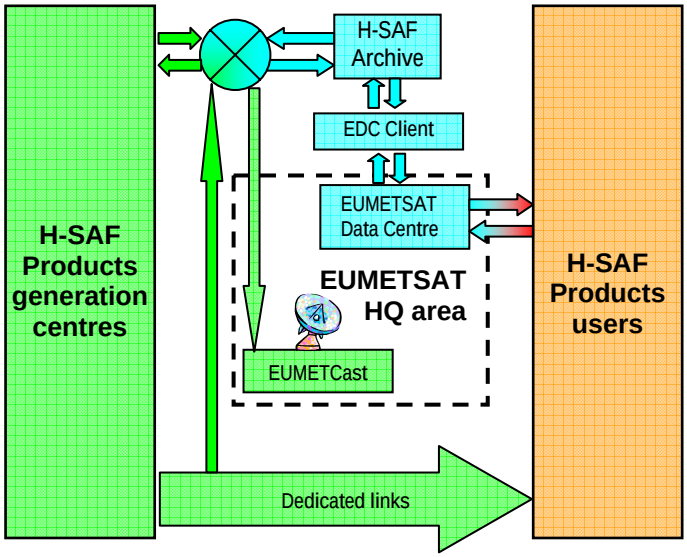

Fig. 05 - H-SAF central archive and distribution facilities.

All data also go to the H-SAF Archive where they can be accessed through the EUMETSAT Data Centre via a Client. Therefore, the H-SAF products may be accessed:

- via EUMETCast in near-real-time (primary access mode);
- off-line via the EUMETSAT Data Centre (most common access mode for the scientific community);
- by dedicate links such as GTS (fastest mode, generally available to operational meteorological services).

It is noted that this scheme is valid only for pre-operational and operational products. For products in development disseminated to beta-users only, or demonstrational products, the distribution ordinarily utilises the ftp servers of the product generation centres, or the CNMCA server. CNMCA also re-disseminate the products generated in other centres, therefore all products can be retrieved from the CNMCA server.

The ftp dissemination stream will continue to be active even after the EUMETCast dissemination becomes effective, both for redundancy purpose, and for users not equipped for EUMETCast reception.

1.4.3 The H-SAF web site

The address of the H-SAF web site is:

- http://www.meteoam.it/modules.php?name=hsaf .

The web site provides:

- general public information on H-SAF
- H-SAF products description
- rolling information on the H-SAF implementation status
- an area for collecting/updating information on the status of satellites and instruments used in H-SAF
- an area to collect Education and Training material
- an area for "forums" (on algorithms, on validation campaigns, etc.)
- indication of useful links (specifically with other SAF's)
- an area for "Frequently Asked Questions" (FAQ) to alleviate the load on the Help desk.

The web site supports operations by providing:

- daily schedule of H-SAF product distribution
- administrative messages on changes of product version (new algorithms, etc.).

The web site contains some basic H-SAF documents (the ATDD, Algorithms Theoretical Definition Document; this Product User Manual, …). However, most working documents (REP-3: Report of the Products Validation Programme; REP-4: Report of the Hydrological Validation Programme; etc.), programmatic documents (PP: Project Plan; URD: User Requirements Documents; etc.) and engineering documents are to be found in the CNMCA ftp server (restricted access; see later for the URL).

It is noted that certain areas of the web sites are protected by an ID ("satelliti") and a password (again, "satelliti").

1.4.4 The Help desk

For any question that cannot be solved by consulting the web site, specifically the FAQ area, the following Help desk is available:

- hsaf user support <us_hsaf@meteoam.it>

When addressing the Help desk, the user should specify in the "Subject" one of the following codes:

- MAN (management)
- PRE (precipitation)
- SOM (soil moisture)
- SNO (snow)
- HYD (hydrology)
- ARC (archive)
- GEN (general).

1.5 The Products User Manual and its linkage to other documents

Product User Manuals are available for each (pre)-operational H-SAF product, for open users, and also for demonstrational products, as necessary for *beta-users*.

Each PUM repeats:

- Chapter 1, this Introduction, that includes common information on Objectives and products, Evolution of H-SAF products, User service and Guide to the Products User Manual;

followed by Chapters specific to each product:

- Chapter 2, that introduces the specific product: Principle of sensing, Satellites utilized, Instrument(s) description, Highlights of the algorithm, Architecture of the products generation chain, Product coverage and appearance;

- Chapter 3, that describes the main product operational characteristics: Horizontal resolution and sampling, Vertical resolution if applicable (only for SM-ASS-1), Observing cycle and time sampling, Timeliness;
- Chapter 4, that provides an overview of the product validation activity: Validation strategy, Global statistics, Product characterisation
- Chapter 5, that provides basic information on product availability: Access modes, Description of the code, Description of the file structure

Although reasonably self-standing, the PUM's rely on other documents for further details. Specifically:

- ATDD (*Algorithms Theoretical Definition Document*), for extensive details on the algorithms, only highlighted here;
- PVR (*Product Validation Report*), for full recount of the validation activity, both the evolution and the latest results.

These documents are structured as this PUM, i.e. one document for each product. They can be retrieved from the CNMCA site:

- ftp://ftp.meteoam.it - username: *hsaf* - password: *00Hsaf* - directory: *hsaf* - folder: *Final-Report-Development-Phase*.

On the same site, it is interesting to consult, although not closely connected to this PUM, the full reporting on hydrological validation experiments (*impact studies*):

- HVR (*Hydrological Validation Report*), spread in 10 Parts, first one on requirements, tools and models, then 8, each one for one participating country, and a last Part with overall statements on the impact of H-SAF products in Hydrology.

1.6 Relevant staff associated to the User Service and to product SM-OBS-2

Table 04 records the names of the persons associated to the development and operation of the User service and of product SM-OBS-2.

Table 04 - Relevant persons associated to the User service and to product SM-OBS-2

User service development and operation			
Adriano Raspanti (Leader)	Centro Nazionale di Meteorologia e Climatologia Aeronautica (CNMCA)	Italy	a.raspanti@meteoam.it
Leonardo Facciorusso			l.facciorusso@meteoam.it
Francesco Coppola			f.coppola@meteoam.it
Giuseppe Leonforte			g.leonforte@meteoam.it
Product Development Team			
Wolfgang Wagner (Leader)	Technische Universität Wien (TU-Wien), Institut für Photogrammetrie und Fernerkundung (IPF)	Austria	ww@ipf.tuwien.ac.at
Stefan Hasenauer			sh@ipf.tuwien.ac.at
Marcela Doubkova			mdo@ipf.tuwien.ac.at
Daniel Sabel			ds@ipf.tuwien.ac.at
Product Operations Team			
Barbara Zeiner (Leader)	Zentralanstalt für Meteorologie und Geodynamik (ZAMG)	Austria	b.zeiner@zamg.ac.at

2. Introduction to product SM-OBS-2

2.1 Principle of sensing

Product SM-OBS-2 (*Small-scale surface soil moisture by radar scatterometer*) results from post-processing of the SM-OBS-1 product extracted by ZAMG from the Global surface soil moisture product distributed by EUMETSAT. Product SM-OBS-1 is based on the radar scatterometer ASCAT embarked on MetOp satellites. The instrument scans the scene in a push-broom mode by six side-looking antennas, three left-hand, three right-hand (see ***Fig. 06***). On each side, the three antennas, looking aside, + 45° and - 45° respectively, provide three views of each earth location under different viewing angles measuring three backscattering coefficients (σ^0, sigma-nought) at slightly different time. Each antenna triplet provides a side swath of 550 km. The two swaths leave a gap (close to the sub-satellite track) of ~ 670 km. Global coverage over Europe is achieved in ~ 1.5 days.

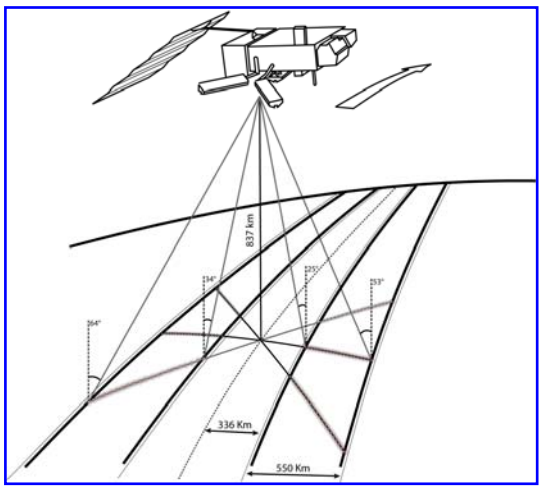

Fig. 06 - Scanning geometry of ASCAT.

The basic instrument sampling distance is 12.5 km. The primary ASCAT observation, sea-surface wind, is processed at 50 km resolution. For soil moisture, processing is performed at 50 km (operational) and 25 km (research) resolution.

For the purpose of SM-OBS-2, the 25-km resolution SM-OBS-1 product is disaggregated and re-sampled at 1-km intervals to better fit hydrological requirements.

The disaggregation process (see ***Fig. 07***) makes use of a fine-mesh layer pre-computed and stored in a parameter database. The fine-mesh information includes backscatter and scaling characteristics derived from SAR imagery from Envisat ASAR operating in the ScanSAR Global monitoring mode.

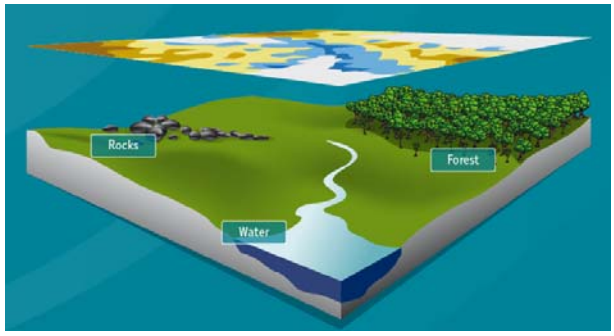

Fig. 07 - Principle of disaggregation by auxiliary data.

2.2 Status of satellites and instruments

The current status of MetOp and Envisat satellites is shown in ***Table 05***.

Table 05 - Current status of MetOp and Envisat satellites (as of March 2010)

Satellite	Launch	End of service	Height	LST	Status	Instruments used in H-SAF
MetOp-A	19 Oct 2006	expected ≥ 2011	817 km	09:30 d	Operational	ASCAT
Envisat	1 Mar 2002	expected ≥ 2013	800 km	10:00 d	Operational	ASAR

Although ASCAT data are not directly used (the processed SM-OBS-1 product is used instead), its main characteristics, that are reflected in SM-OBS-2, are recorded in the ***Table 06***. The main features of ASAR, that is used for building the database of disaggregation parameters, are recorded in ***Table 07***. Envisat is managed by ESA, and ASAR data are available from the ESA archives. Since ASAR is operated in time sharing among several modes, building the database for SM-OBS-2 is a lengthy undertaking.

Table 06 - Main features of ASCAT

ASCAT	Advanced Scatterometer
Satellites	MetOp-A, MetOp-B, MetOp-C
Status	Operational - Utilised in the period: 2006 to ~ 2021
Mission	Sea surface wind vector. Also large-scale soil moisture
Instrument type	Radar scatterometer - C-band (5.255 GHz), side looking both left and right. 3 antennas on each side
Scanning technique	Two 550-km swaths separated by a 700-km gap along-track. 3 looks each pixel (45, 90 and 135° azimuth)
Coverage/cycle	Global coverage in 1.5 days
Resolution	Best quality: 50 km – standard quality: 25 km – basic sampling: 12.5 km
Resources	Mass: 260 kg - Power: 215 W - Data rate: 42 kbps

Table 07 - Main features of ASAR

ASAR	Advanced Synthetic Aperture Radar - SAR mode
Satellite	Envisat
Status	Operational - Utilised in the period 2002 to ~ 2013
Mission	High-resolution all-weather multi-purpose imager for ocean, land and ice
Instrument type	Imaging radar - C-band SAR, frequency 5.331 GHz, multi-polarisation and variable pointing/resolution
Scanning technique	Side-looking, 15-45° off-nadir, swath 100 to 405 km, depending on operation mode - See table
Coverage/cycle	Global coverage in 5 day for the 'global monitoring' mode (if used for 70 % of the time); in longer periods for other operation modes, up to 3 months
Resolution	30 m to 1 km, depending on operation mode - See table
Resources	Mass: 832 kg - Power: 1400 W - Data rate: 100 Mbps

Operation mode	Resolution	Swath	Field of regard	Polarisation
Stripmap	30 m	100 km	485 km	HH or VV
ScanSAR alternating pol	30 m	100 km	485 km	VV/HH, HH/HV, VV/VH
ScanSAR wide swath	150 m	405 km	405 km	HH or VV
ScanSAR wide swath	150 m	405 km	405 km	HH or VV
ScanSAR global monitoring	1 km	405 km	405 km	HH or VV
Wave	30 m	5 x 5 km^2 imagettes sampled at 100 km intervals		HH or VV

2.3 Highlights of the algorithm

The baseline algorithm for SM-OBS-2 processing is described in ATDD-08. Only essential elements are highlighted here.

Fig. 08 illustrates the flow chart of the SM-OBS-2 processing chain. There is an off-line activity to prepare the disaggregation parameters and a real-time activity to exploit the satellite data for the product

In the off-line pre-processing step, Envisat ASAR Global Mode (ASAR GM) datasets are re-sampled to the geometry of the output product over a predefined European grid. All the parameters are stored in a European parameter database. When it comes to product generation itself with the software WARP-H, the disaggregated product is calculated with the restored European parameter database in near-real time.

The idea of the disaggregation approach is to use a temporal stability concept. This concept has been established originally in hydrology, but has been used in different applications as well. Introduced by Vauchaud et al. 1985[1], it is used to estimate representative soil moisture stations within a catchment area. With this method, the relation between a single local in-situ soil moisture station and the regional mean of all in-situ soil moisture stations can be described. Since then the method has for example been used by Martínez-Fernández and Ceballos 2005[2] to describe the relation between local in-situ soil

[1] Vauchaud G., A. Passerat de Silans, P. Balabanis and M. Vauclin, 1985: "Temporal stability of spatially measured soil water probability density function". *Soil Science Society of America* **49**: 822-828.

[2] Martínez-Fernández J. and A. Ceballos, 2005: "Mean soil moisture estimation using temporal stability analysis". *Journal of Hydrology* **312**: 28-38.

moisture data and regional soil moisture trends. If the spatial coverage of ASAR GM data is not sufficient for regions in Europe, the product SM-OBS-2 is not defined there (currently the case for UK, parts of the Benelux countries and the Alpine parts of Italy) mainly due to conflicting operating modes of the ENVISAT instruments. As development is an ongoing process, the product will continue to be re-tuned as the acquisition and coverage of ASAR GM grows.

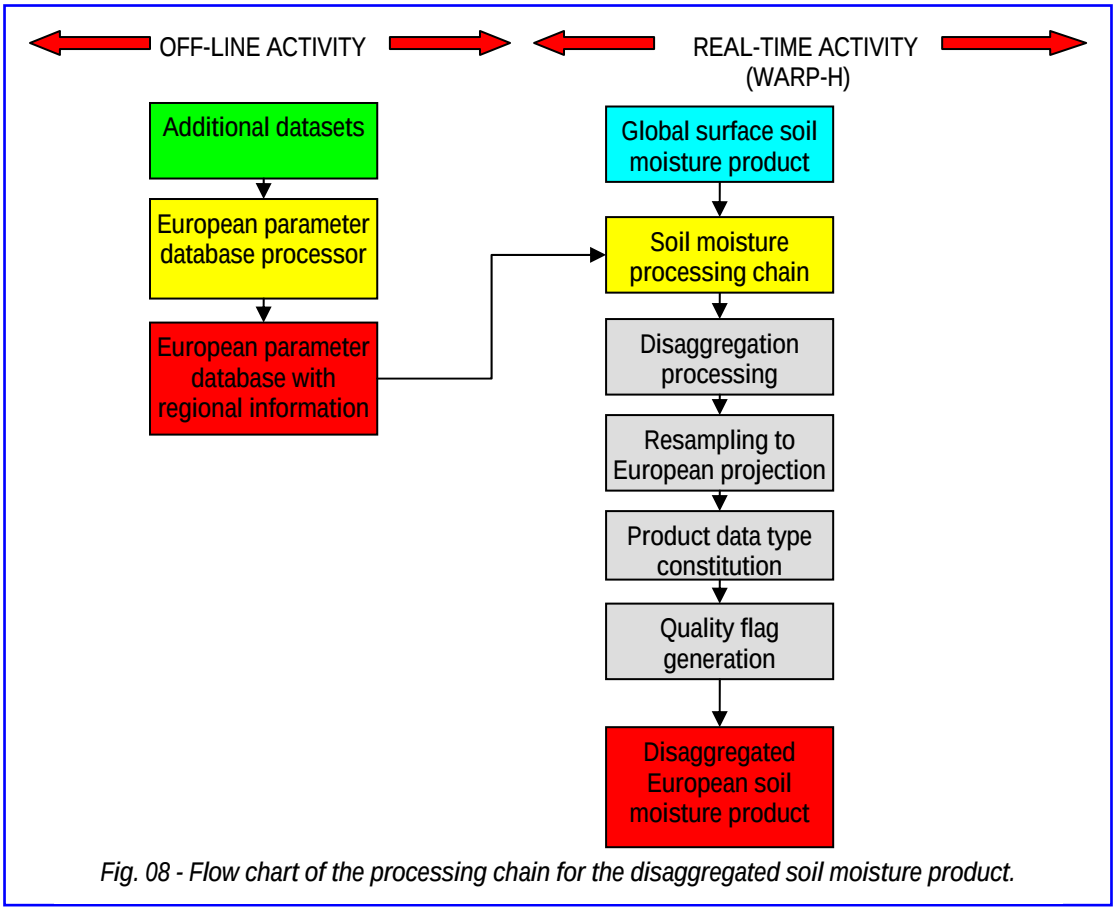

Fig. 08 - Flow chart of the processing chain for the disaggregated soil moisture product.

2.4 Architecture of the products generation chain

The architecture of the SM-OBS-2 product generation chain is shown in ***Fig. 09***. The figure includes mention of the primary source of satellite data, the Global surface soil moisture product generated by EUMETSAT and disseminated via EUMETCast; and of the source for disaggregation parameters, the ASAR instrument on Envisat, with data available from the ESA archive.

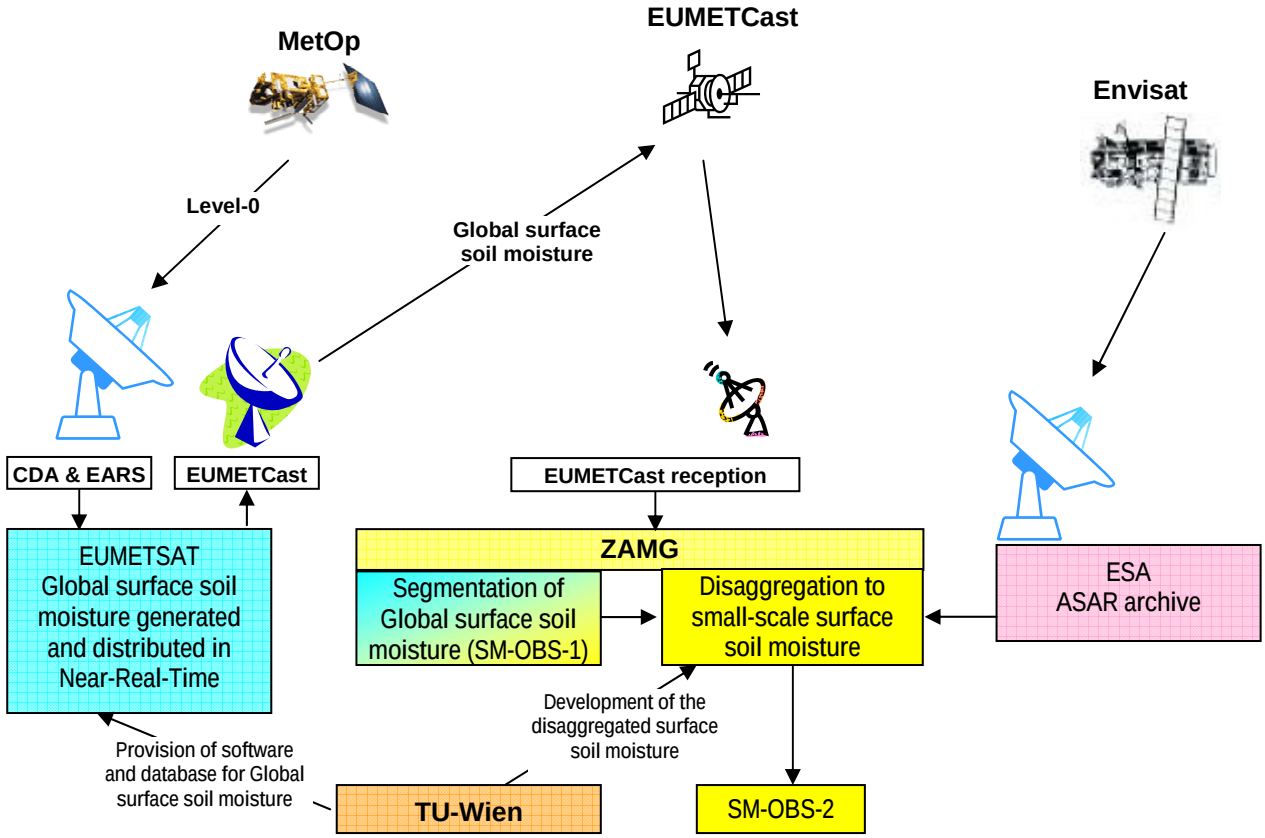

Fig. 09 - Conceptual architecture of the SM-OBS-2 production chain.

2.5 Product coverage and appearance

Fig. 10 shows an example of downscaled surface soil moisture at 1 km resolution for Europe representing a 3-minute strip of a full ASCAT orbit. The two sub-swaths can be clearly identified, no-data values (e.g. over the sea) are masked out.

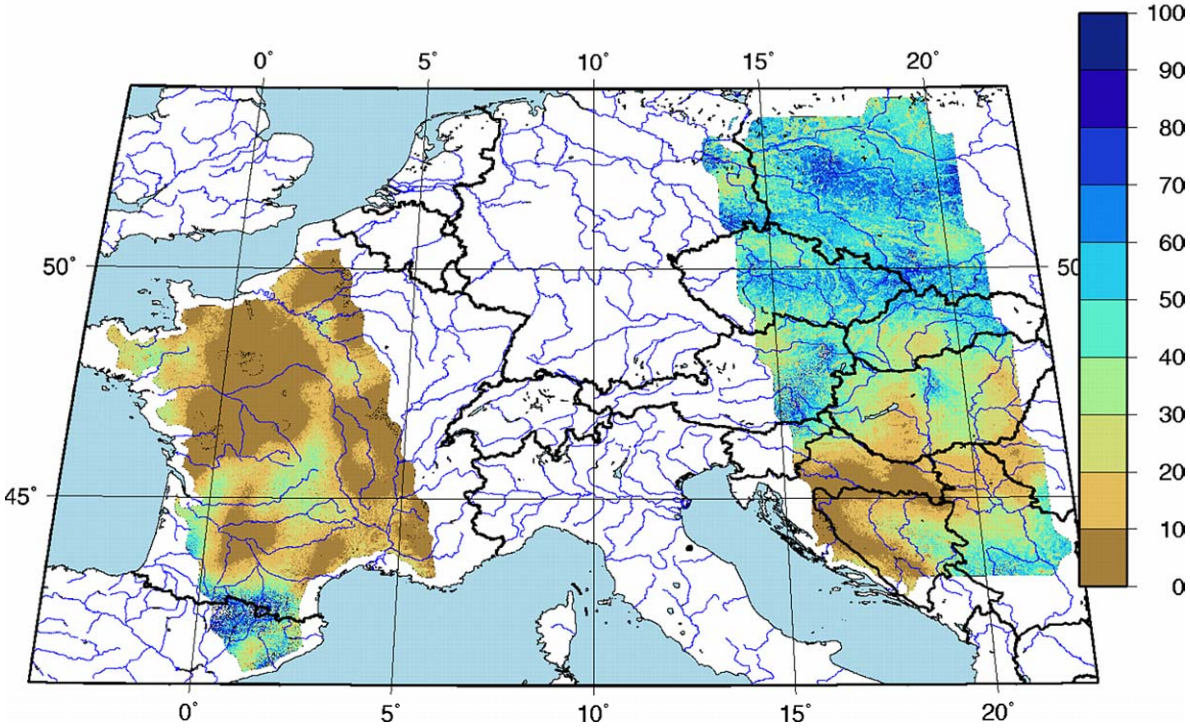

Fig. 10 - Example of small-scale surface soil moisture (SM-OBS-2) from ASCAT. Note the two side swaths (550 km each) and the 670 km gap in between. MetOp-A, 30 September 2009, 20:12 UTC.

Fig. 11 compares the 1-km sampled SM-OBS-2 with the 25-km original resolution of SM-OBS-1.

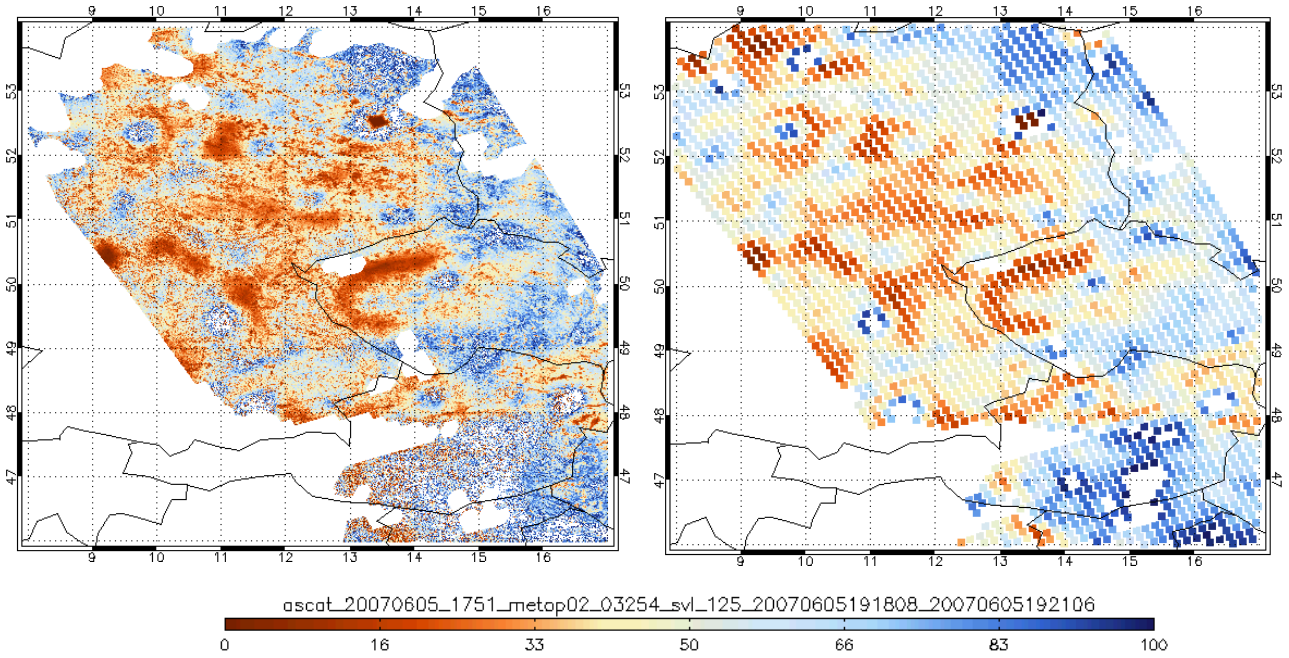

Fig. 11 - Detailed view of SM-OBS-2 over central Europe (left panel). MetOp-A, 5 June 2007, 19:18 - 19:19 UTC. Area of ~880 x 650 km². For comparison, the SM-OBS-1 product is shown (right panel). No-data values are masked.

3. Product operational characteristics

3.1 Horizontal resolution and sampling

The *horizontal resolution (Δx)* is the convolution of several features (sampling distance, degree of independence of the information relative to nearby samples, …). To simplify matters, it is generally agreed to refer to the sampling distance between two successive product values, assuming that they carry forward reasonably independent information. The horizontal resolution descends from the instrument Instantaneous Field of View (*IFOV*), sampling distance (*pixel*), Modulation Transfer Function (*MTF*) and number of pixels to co-process for filtering out disturbing factors (e.g. clouds) or improving accuracy. It may be appropriate to specify both the resolution Δx associated to independent information, and the *sampling distance*, useful to minimise aliasing problems when data have to undertake resampling (e.g., for co-registration with other data).

In the case of SM-OBS-2, the effective resolution is controlled by the originating product, SM-OBS-1, therefore the worst-case figure representative of the SM-OBS-2 resolution is: $\Delta x = 25$ km. However, the disaggregation process performs re-sampling at 1 km intervals, that therefore would constitute the resolution in best conditions. The effectiveness of disaggregation depends on the availability and the effectiveness of the disaggregation parameters, that in certain areas may be of poor quality. The SM-OBS-2 resolution is therefore ***$\Delta x = 1 \div 25$ km***. The sampling distance is ***1 km***.

3.2 Vertical resolution if applicable

The *vertical resolution (Δz)* also is defined by referring to the vertical sampling distance between two successive product values, assuming that they carry forward reasonably independent information. The vertical resolution descends from the exploited remote sensing principle and the instrument number of channels, or spectral resolution. It is difficult to be estimated *a-priori*: it is generally evaluated *a-posteriori* by means of the validation activity.

The only product in H-SAF that provides profiles (below surface) is SM-ASS-1 (*Volumetric soil moisture (roots region) by scatterometer assimilation in NWP model*).

3.3 Observing cycle and time sampling

The *observing cycle (Δt)* is defined as the average time interval between two measurements over the same area. In general the area is, for GEO, the disk visible from the satellite, for LEO, the Globe. In the case of H-SAF we refer to the European area shown in Fig. 04. In the case of LEO, the observing cycle depends on the instrument swath and the number of satellites carrying the addressed instrument.

The ASCAT swath is 550 + 550 km on the two sides, with a 670 km gap in between. The gap left by ascending orbits is mostly filled by descending orbits. In average the observing cycle over Europe is ***Δt ~ 36 h***, improving with latitude. However, areas where disaggregation parameters are not available, are not processed, therefore the SM-OBS-2 maps leave several gaps of coverage. These gaps will progressively reduce along with progress of the ASAR coverage [and ultimately with the availability of the ESA/GMES Sentinel-1: launch scheduled in 2012]

3.4 Timeliness

The *timeliness (δ)* is defined as the time between observation taking and product available at the user site assuming a defined dissemination mean. The timeliness depends on the satellite transmission facilities, the availability of acquisition stations, the processing time required to generate the product and the reference dissemination means. In the case of H-SAF the future dissemination tool is EUMETCast, but currently we refer to the availability on the FTP site.

The product is generated shortly after reception of the Global product from EUMETSAT via EUMETCast, that has a timeliness of ~ 1.5 h. The processing time is less than 20 minutes. Adding 10 min for distribution we have: ***δ ~ 2 h***.

4. Product validation

4.1 Validation strategy

Whereas the previous operational characteristics have been evaluated on the base of system considerations (number of satellites, their orbits, access to the satellite) and instrument features (IFOV, swath, MTF and others), the evaluation of accuracy requires validation, i.e. comparison with the ground truth or with something assumed as "true". SM-OBS-2, as any other H-SAF product, has been submitted to validation entrusted to a number of institutes (see ***Fig. 12***).

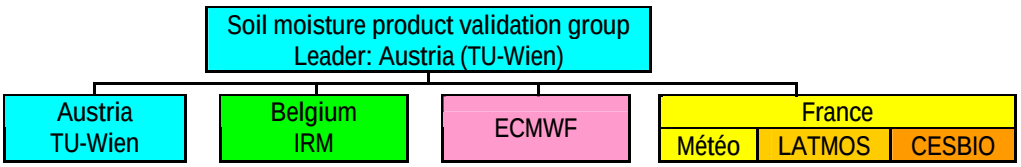

Fig. 12 - Structure of the Soil moisture products validation team.

Calibration and validation of soil moisture observation from space is a hard work, especially because ground systems are essentially based on very sparse in-field measurements. Comparison with results of numerical models obviously suffer of the limited skill of NWP in predicting soil moisture (a very downstream product that passes through quantitative precipitation forecast, that certainly is not the most accurate product of NWP). A mixture of several techniques is generally used, and the results change with the climatic situation and the status of soil.

Detailed report of the product validation activity for product SM-OBS-2 is provided as document:

- PVR-08: Product Validation Report for SM-OBS-2.

In this PUM-08 only summary results are provided, mainly aiming at characterising the product quality under different geographical/climatological conditions (those in the countries of the participating validation Units) and different seasons.

4.2 Summary of results

Prototypes of SM-OBS-2 have been available since May 2009, and since then the product has been distributed and submitted for validation. User requirements for soil moisture observation have been stated in terms of RMSE ($m^3 \cdot m^{-3}$). The results reported in ***Table 08*** are split by countries and campaigns, separately for field measurements and comparison with the output of hydrological models. The following statistical scores are reported (for more information, see PVR-08):

- ME: Mean Error
- SD: Standard Deviation
- RMSE: Root Mean Square Error
- CC: Correlation coefficient.

Table 08 - Statistical scores for SM-OBS-2

SM-OBS-2		Region	V.	Period	N. of sites	ME ($m^3 m^{-3}$)	SD ($m^3 m^{-3}$)	RMSE ($m^3 m^{-3}$)	CC
In-situ measurements	Météo-France	France (South-West)	2	01/2007-12/2008	13	-	-	-	0.86 (max)
	TU-Wien & Lippmann	Luxembourg (Bibeschbach)	2a	01/2007-05/2008	40	-	-	0.10 - 0.11	0.88 - 0.89
	LATMOS	France (Grand Morin)	2a	01/2007-12/2008	2	-	-	-	-
	LATMOS	Tunisia (Merguellil)	2a	01/2009-05/2009	1	-	-	-	-
	TU-Wien & CNR-IRPI	Luxembourg (Bibeschbach)	3b	01/2007-12/2008	2	Sfc: -0.18 Root: -0.18	-	Sfc: 0.29 Root: 0.14	Sfc: 0.58 Root: 0.84
	TU-Wien & CNR-IRPI	Italy (Tiber)	3b	01/2007-12/2008	1	Sfc: -0.03 Root: -0.04	-	Sfc: 0.30 Root: 0.15	Sfc: 0.46 Root: 0.85
Hydro. Model	RMI	Belgium (Demer	2a	01/2007-06/2009	709 (samples)	0.08	-	0.30	0.75
	RMI	Belgium (Ourthe)	2a	01/2007-06/2009	685 (samples)	0.21	-	0.29	0.76
	TU-Wien & CNR-IRPI	Italy (Tiber)	3a	01/2007-12/2008	1	Sfc: -0.12 Root: -0.12	-	Sfc: 0.22 Root: 0.14	Sfc: 0.74 Root: 0.84

5. Product availability

5.1 Site

SM-OBS-2 will be available via EUMETCast (when authorized) and via FTP (after log in).

The current access is via FTP at the following site:

- URL: ftp://ftp.meteoam.it
- username: *hsaf*
- password: *00Hsaf* .

The data are loaded in the directory:

- *products*, for near-real-time dissemination and data holding for nominally 1-2 months, often more;

Older data are stored in the permanent H-SAF archive, and can be recovered on request.

Quick-looks of the latest 3 days of SM-OBS-2 maps, covering some H-SAF areas, can be viewed on the H-SAF web site:

- http://www.meteoam.it/modules.php?name=hsaf
- directory: *products*, sub-directory: *soil moisture*, ID: *satelliti*, password: *satelliti*.

5.2 Formats and codes

SM-OBS-2 is codes as:

- the digital data: BUFR
- the image-like maps: PNG

In the directory "*utilities*", the folder *Bufr_decode* provides the instructions for reading the digital data. In addition, the output description of SM-OBS-2 is provided in Appendix.

5.3 Description of the files

The data are available under

- Directory: *products*
- Sub-directory: *h08*
- Two folders:
  - h08_cur_mon_buf
  - h08_cur_mon_png

Table 09 summarises the situation and provides the information on the file structure.

Table 09 - Summary instructions for accessing SM-OBS-2 data

URL: ftp://ftp.meteoam.it	username: *hsaf*	password: *00Hsaf*	directory: *products*
Product identifier: *h08*. Folders under h08:	h08_cur_mon_buf	digital data of current months	
	h08_cur_mon_png	Images of current months	
Files description of current month:	h08_yyyymmdd_hhmmss_satellite_nnnnn_ZAMG.buf.gz	digital data	
	h08_yyyymmdd_hhmmss_satellite_nnnnn_ZAMG.png	image data	
yyyymmdd: year, month, day hhmmss: hour, minute, second of first scan line (ascending: southernmost; descending: northernmost) satellite: name of the satellite (currently: metopa) nnnnn: orbit number			

5.4 Condition for use

All H-SAF products are owned by EUMETSAT, and the EUMETSAT SAF Data Policy applies. They are available for all users free of charge.

Users should recognise the respective roles of EUMETSAT, the H-SAF Leading Entity and the H-SAF Consortium when publishing results that are based on H-SAF products. EUMETSAT's ownership of and intellectual property rights into the SAF data and products is best safeguarded by simply displaying the words "**© EUMETSAT**" under each of the SAF data and products shown in a publication or website.

See Appendix: *SM-OBS-2 Output description*

Appendix: SM-OBS-2 Output description

The Soil moisture products are delivered in BUFR (Binary Universal Form for data Representation) format, which is a continuous bit stream made of sequence of octets encoded according to the current WMO tables. (A bufr toolbox and a manual for the user can be found at the ECMWF homepage).

The BUFR template valid at the time of this writing is:

1 006001 LONGITUDE (HIGH ACCURACY)
2 005001 LATITUDE (HIGH ACCURACY)
3 005001 LATITUDE (HIGH ACCURACY)
4 103000 (delayed replication of 4 BUFR descriptors)
5 031002 EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR
6 040001 SURFACE SOIL MOISTURE (MS)
7 040002 ESTIMATED ERROR IN SURFACE SOIL MOISTURE
8 040005 SOIL MOISTURE CORRECTION FLAG
9 040006 SOIL MOISTURE PROCESSING FLAG

Each of these telegrams represents an image column. Taking into account the results of the preceding, 120 of these telegrams are packed together in a BUFR „multi subset".

Table 1 and

Table 2 show the possible values for flags 40005 and 40006, according to WMO definitions. Yet, only values highlighted in red are at present relevant for the 1km surface soil moisture product.

Table 1: The WMO codes for BUFR flag No. 40005 - Soil moisture correction flags. NOTE: The nominal range for the surface soil moisture is 0% - 100%. In extreme cases, the extrapolated backscatter at 40 degrees incidence angle may exceed the dry or the wet backscatter reference. In these cases, the value provided by the measurement process of surface soil moisture is, respectively, less than 0% or more than 100%.

Bit No.	Meaning
1	Soil moisture between -20% and 0%
2	Soil moisture between 100% and 120%
3	Correction of wet backscatter reference
4	Correction of dry backscatter reference
5	Correction of volume scattering in sand
6-7	Reserved
All 8	Missing value

Table 2: The WMO codes for BUFR flag No. 40006 - Soil moisture processing flags. NOTE: See Note under Flag No. 40005 (Table 1)

Bit No.	Meaning
1	Not soil
2	Sensitivity to soil moisture below limit
3	Azimuthal noise above limit
4	Backscatter Fore-Aft beam out of range
5	Slope Mid-Fore beam out of range
6	Slope Mid-Aft beam out of range
7	Soil moisture below -20%
8	Soil moisture above 120%
9-15	Reserved
All 16	Missing value

.

The first telegram in the operational BUFR files is different and provides the user with some information useful for deciding whether the file actually has some data of interest in it and is worth further decoding (in particular, the prologue reports the geographical coverage of the dataset). Template of the prologue:

1 025061 SOFTWARE IDENTIFICATION AND VERSION NUMBER
2 025062 DATABASE IDENTIFICATION
3 006002 LONGITUDE (COARSE ACCURACY)
4 006002 LONGITUDE (COARSE ACCURACY)
5 005002 LATITUDE (COARSE ACCURACY)
6 005002 LATITUDE (COARSE ACCURACY)

For those users which are not so familiar with BUFR a program which converts the operational 1 km soil moisture product (SM-OBS 2) file into netCDF is attached here:

```
PROGRAM BUFR2NETCDF
!
! PURPOSE: DECODE THE OPERATIONAL 1 KM - SOIL MOISTURE PRODUCT IN BUFR FORMAT,
! RE-ENCODE IN netCDF FORMAT
! EXTERNALS: BUFREX, BUSEL2, BUS0123, PBBUFR, PBOPEN, PBCLOSE
! COMPILATION: f90 -o bufr2netcdf bufr2netcdf.F90 -L$NETCDF_libdir -lnetcdf -L$HDF_libdir -lhdf5_hl -lhdf5 -
L$BUFR_libdir -lbufr
! CALL: bufr2netcdf <BUFR file's name>
! OUTPUT: NetCDF file, with extension (i.e. everything after the last dot) replaced by 'nc'
! (h08_20090816_105100_metopa_14658_ZAMG.buf becomes h08_20090816_105100_metopa_14658_ZAMG.nc)
! AUTHOR: Alexander Jann / ZAMG
! DATE: 04/11/09
!
USE netcdf
IMPLICIT NONE
INTEGER :: I, INDEX1D, INDEX2D, ERR, SUBSET_NR, JUMP, JUMP_SM, N, NLAT, NLON, NR_PIXELS,
UNIT
! BUFR
INTEGER, PARAMETER :: JSUP=9, JSEC0=3, JSEC1=40, JSEC2=4096 , JSEC3=4, &
JSEC4=2, JELEM=160000, JBUFL=512000, KELEM=160000, KVALS=4096000, JBYTE=440000
INTEGER :: KSUP(JSUP), KSEC0(JSEC0), KSEC1(JSEC1)
INTEGER :: KSEC2(JSEC2), KSEC3(JSEC3), KSEC4(JSEC4)
INTEGER :: KBUFL, KDLEN, KEL, KTDLEN, KTDEXL, KTDEXP
INTEGER, DIMENSION(JBUFL) :: KBUFF
REAL*8, DIMENSION(KVALS) :: VALUES
INTEGER, DIMENSION(JELEM) :: KTDLST
CHARACTER (LEN=64), DIMENSION(KELEM) :: CNAMES
CHARACTER (LEN=24), DIMENSION(KELEM) :: CUNITS
CHARACTER (LEN=80), DIMENSION(KELEM) :: CVALS
! IDs for the netCDF file, dimensions, and variables...
INTEGER :: NCID, LON_DIMID, LAT_DIMID, DIMIDS(2)
INTEGER :: LAT_VARID, LON_VARID
INTEGER :: SOMO_VARID, SOMO_ERR_VARID, SOMO_FLAG5_VARID, SOMO_FLAG6_VARID
! ...ranges...
REAL :: SOMO_RANGE(2) = (/0., 100./)
INTEGER*2 :: FLAG_RANGE(2) = (/0, 255/)
! ...names.
CHARACTER (LEN = *), PARAMETER :: LAT_NAME = "latitude", LON_NAME = "longitude"
CHARACTER (LEN = *), PARAMETER :: UNITS = "units", SOMO_UNITS = "%"
CHARACTER (LEN = *), PARAMETER :: LAT_UNITS = "degrees_north", LON_UNITS = "degrees_east"
! SM data
REAL, DIMENSION(:), ALLOCATABLE :: SOMO, SOMO_ERR, LAMBDA, PHI
INTEGER*2, DIMENSION(:), ALLOCATABLE :: FLAG_40005, FLAG_40006
CHARACTER (LEN=255) :: IFILNAM, OFILNAM
DATA KSEC0,KSEC2,KSEC3,KSEC4,KTDLST &
/JSEC0*0,JSEC2*0,JSEC3*0,JSEC4*0,JELEM*0/
! 1. Open BUFR file
! ------------------------------------
CALL GETARG(1,IFILNAM)
ERR=0
CALL PBOPEN(UNIT,IFILNAM,'R',ERR)
IF ( ERR == -1 ) STOP 'OPEN FAILED'
```

```
IF ( ERR == -2 ) STOP 'INVALID FILE NAME'
IF ( ERR == -3 ) STOP 'INVALID OPEN MODE SPECIFIED'
! 2. Decode prologue
! --------------------------------------
ERR=0
CALL PBBUFR(UNIT,KBUFF,JBYTE*4,KBUFL,ERR)
IF (ERR /= 0) STOP 'cannot even read the prologue :-('
KBUFL=KBUFL/4+1
CALL BUS0123(KBUFL, KBUFF, KSUP, KSEC0, KSEC1, KSEC2, KSEC3, ERR)
KEL=KVALS/KSEC3(3)
IF (KEL > KELEM) KEL=KELEM
! Expand BUFR message.
CALL BUFREX(KBUFL, KBUFF, KSUP, KSEC0, KSEC1, KSEC2, KSEC3, KSEC4, &
KEL, CNAMES, CUNITS, KVALS, VALUES, CVALS, ERR)
NLON=NINT((VALUES(4)-VALUES(3))/0.00416667) ! maximum; # of columns may actually be less
NLAT=NINT((VALUES(6)-VALUES(5))/0.00416667)
NR_PIXELS=NLON*NLAT
ALLOCATE(SOMO(1:NR_PIXELS))
ALLOCATE(SOMO_ERR(1:NR_PIXELS))
ALLOCATE(FLAG_40005(1:NR_PIXELS))
ALLOCATE(FLAG_40006(1:NR_PIXELS))
ALLOCATE(LAMBDA(1:NLON))
ALLOCATE(PHI(1:NLAT))
! 3. Decode actual soil moisture data.
! --------------------------------------
INDEX1D=1
INDEX2D=1
MSSLOOP: DO
KBUFL=0
CALL PBBUFR(UNIT,KBUFF,JBYTE*4,KBUFL,ERR)
IF (ERR == -1) THEN
CALL PBCLOSE(UNIT,ERR)
EXIT MSSLOOP
ENDIF
IF (ERR == -2) STOP 'FILE HANDLING PROBLEM'
IF (ERR == -3) STOP 'ARRAY TOO SMALL FOR PRODUCT'
N=N+1
KBUFL=KBUFL/4+1
CALL BUS0123(KBUFL, KBUFF, KSUP, KSEC0, KSEC1, KSEC2, KSEC3, ERR)
IF (ERR /= 0) THEN
PRINT*,'ERROR IN BUS0123: ',ERR, 'FOR MESSAGE NUMBER ',N
ERR=0
CYCLE MSSLOOP
ENDIF
KEL=KVALS/KSEC3(3)
IF (KEL > KELEM) KEL=KELEM
! Expand BUFR message.
CALL BUFREX(KBUFL, KBUFF, KSUP, KSEC0, KSEC1, KSEC2, KSEC3, KSEC4, &
KEL, CNAMES, CUNITS, KVALS, VALUES, CVALS, ERR)
IF (ERR /= 0) CALL EXIT(2)
ISSLOOP: DO SUBSET_NR=0,KSUP(6)-1
JUMP=SUBSET_NR*KEL
CALL BUSEL2(SUBSET_NR+1,KEL,KTDLEN,KTDLST,KTDEXL,KTDEXP,CNAMES, &
CUNITS,ERR)
LAMBDA(INDEX1D)=VALUES(JUMP+1)
IF (INDEX1D == 1) THEN
DO I=1,NLAT
PHI(I)=VALUES(JUMP+2)+0.00416667*(I-1)
END DO
ENDIF
INDEX1D=INDEX1D+1
! Resolve replication
```

```
JUMP_SM=JUMP+5
DO I=1,VALUES(JUMP+4)
SOMO(INDEX2D)=VALUES(JUMP_SM)
SOMO_ERR(INDEX2D)=VALUES(JUMP_SM+1)
FLAG_40005(INDEX2D)=VALUES(JUMP_SM+2)
FLAG_40006(INDEX2D)=VALUES(JUMP_SM+3)
JUMP_SM=JUMP_SM+4
INDEX2D=INDEX2D+1
END DO
END DO ISSLOOP
END DO MSSLOOP
! 4. Create the netCDF file and variables.
! ----------------------------------------
OFILNAM=IFILNAM(1:SCAN(IFILNAM,'.',.TRUE.))//'nc'
CALL CHECK( NF90_CREATE(OFILNAM, NF90_HDF5, NCID) )
! Define the dimensions.
NLON=INDEX1D-1
CALL CHECK( NF90_DEF_DIM(NCID, LAT_NAME, NLAT, LAT_DIMID) )
CALL CHECK( NF90_DEF_DIM(NCID, LON_NAME, NLON, LON_DIMID) )
! Define the coordinate variables. They will hold the coordinate
! information, that is, the latitudes and longitudes. A varid is
! returned for each.
CALL CHECK( NF90_DEF_VAR(NCID, LAT_NAME, NF90_FLOAT, LAT_DIMID, LAT_VARID) )
CALL CHECK( NF90_DEF_VAR(NCID, LON_NAME, NF90_FLOAT, LON_DIMID, LON_VARID) )
! Assign units attributes to coordinate var data. This attaches a
! text attribute to each of the coordinate variables, containing the
! units.
CALL CHECK( NF90_PUT_ATT(NCID, LAT_VARID, UNITS, LAT_UNITS) )
CALL CHECK( NF90_PUT_ATT(NCID, LON_VARID, UNITS, LON_UNITS) )
! The dimids array is used to pass the dimids of the dimensions of
! the netCDF variables. All netCDF variables we are
! creating share the same two dimensions.
DIMIDS = (/ LON_DIMID, LAT_DIMID /)
! Define the netCDF variables for the soil moisture data.
CALL CHECK( NF90_DEF_VAR(NCID, "soil_moisture", NF90_FLOAT, DIMIDS, SOMO_VARID) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_VARID, UNITS, SOMO_UNITS) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_VARID, "valid_range", SOMO_RANGE) )
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CALL CHECK( NF90_DEF_VAR_DEFLATE(NCID, SOMO_VARID, 1, 1, 9) )
CALL CHECK( NF90_DEF_VAR(NCID, "soil_moisture_error", NF90_FLOAT, DIMIDS, SOMO_ERR_VARID) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_ERR_VARID, UNITS, SOMO_UNITS) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_ERR_VARID, "valid_range", SOMO_RANGE) )
CALL CHECK( NF90_DEF_VAR_DEFLATE(NCID, SOMO_ERR_VARID, 1, 1, 9) )
CALL CHECK( NF90_DEF_VAR(NCID, "soil_moisture_correction_flag", NF90_SHORT, DIMIDS,
SOMO_FLAG5_VARID) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_FLAG5_VARID, "valid_range", FLAG_RANGE) )
CALL CHECK( NF90_DEF_VAR_DEFLATE(NCID, SOMO_FLAG5_VARID, 1, 1, 9) )
CALL CHECK( NF90_DEF_VAR(NCID, "soil_moisture_processing_flag", NF90_SHORT, DIMIDS,
SOMO_FLAG6_VARID) )
CALL CHECK( NF90_PUT_ATT(NCID, SOMO_FLAG6_VARID, "valid_range", FLAG_RANGE) )
CALL CHECK( NF90_DEF_VAR_DEFLATE(NCID, SOMO_FLAG6_VARID, 1, 1, 9) )
! End define mode.
CALL CHECK( NF90_ENDDEF(NCID) )
! 5. Write the netCDF file, clean up and leave.
! ---------------------------------------------
! Write the coordinate variable data. This will put the latitudes
! and longitudes of our data grid into the netCDF file.
CALL CHECK( NF90_PUT_VAR(NCID, LAT_VARID, PHI) )
CALL CHECK( NF90_PUT_VAR(NCID, LON_VARID, LAMBDA(1:NLON)) )
! Write the soil moisture data to the netCDF file
CALL CHECK( NF90_PUT_VAR(NCID, SOMO_VARID, TRANSPOSE(RESHAPE(SOMO(1:INDEX2D-
1),(/NLAT, NLON/)))) )
```

```
CALL CHECK( NF90_PUT_VAR(NCID, SOMO_ERR_VARID,
TRANSPOSE(RESHAPE(SOMO_ERR(1:INDEX2D-1),(/NLAT, NLON/)))) )
CALL CHECK( NF90_PUT_VAR(NCID, SOMO_FLAG5_VARID,
TRANSPOSE(RESHAPE(FLAG_40005(1:INDEX2D-1),(/NLAT,
NLON/)))) )
CALL CHECK( NF90_PUT_VAR(NCID, SOMO_FLAG6_VARID,
TRANSPOSE(RESHAPE(FLAG_40006(1:INDEX2D-1),(/NLAT,
NLON/)))) )
! Close the file.
CALL CHECK( NF90_CLOSE(NCID) )
DEALLOCATE(SOMO_ERR)
DEALLOCATE(SOMO)
DEALLOCATE(FLAG_40005)
DEALLOCATE(FLAG_40006)
DEALLOCATE(LAMBDA)
DEALLOCATE(PHI)
WRITE(*,*) "*** SUCCESS in writing ",OFILNAM
CONTAINS
SUBROUTINE CHECK(STATUS)
INTEGER, INTENT ( IN) :: STATUS
IF (STATUS /= NF90_NOERR) THEN
WRITE(*,*) NF90_STRERROR(STATUS)
        STOP 2
END IF
END SUBROUTINE CHECK
END PROGRAM
```